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(54) **EXTERNAL TRAY HOSE WITH INTEGRATED PUMP**

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F04D 3/00 (2006.01)
(Continued)

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CPC ***F04D 29/586*** (2013.01); ***F04D 3/00*** (2013.01); ***F04D 13/12*** (2013.01); ***F04D 15/0088*** (2013.01); ***F04D 29/528*** (2013.01)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,714,558 A 12/1987 Barbee et al.
5,419,594 A 5/1995 Nelms
(Continued)

FOREIGN PATENT DOCUMENTS

GB 2495547 A * 4/2013 .... H02K 21/185
GB 2566689 A 3/2019
(Continued)

OTHER PUBLICATIONS

Sidewindercomputers, "Bitspower Shining Silver Rotary 90 Fitting # BP-LRII—G 1/4 Threads," 2019, 1-Page.

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Assistant Examiner — Jackson N Gillenwaters
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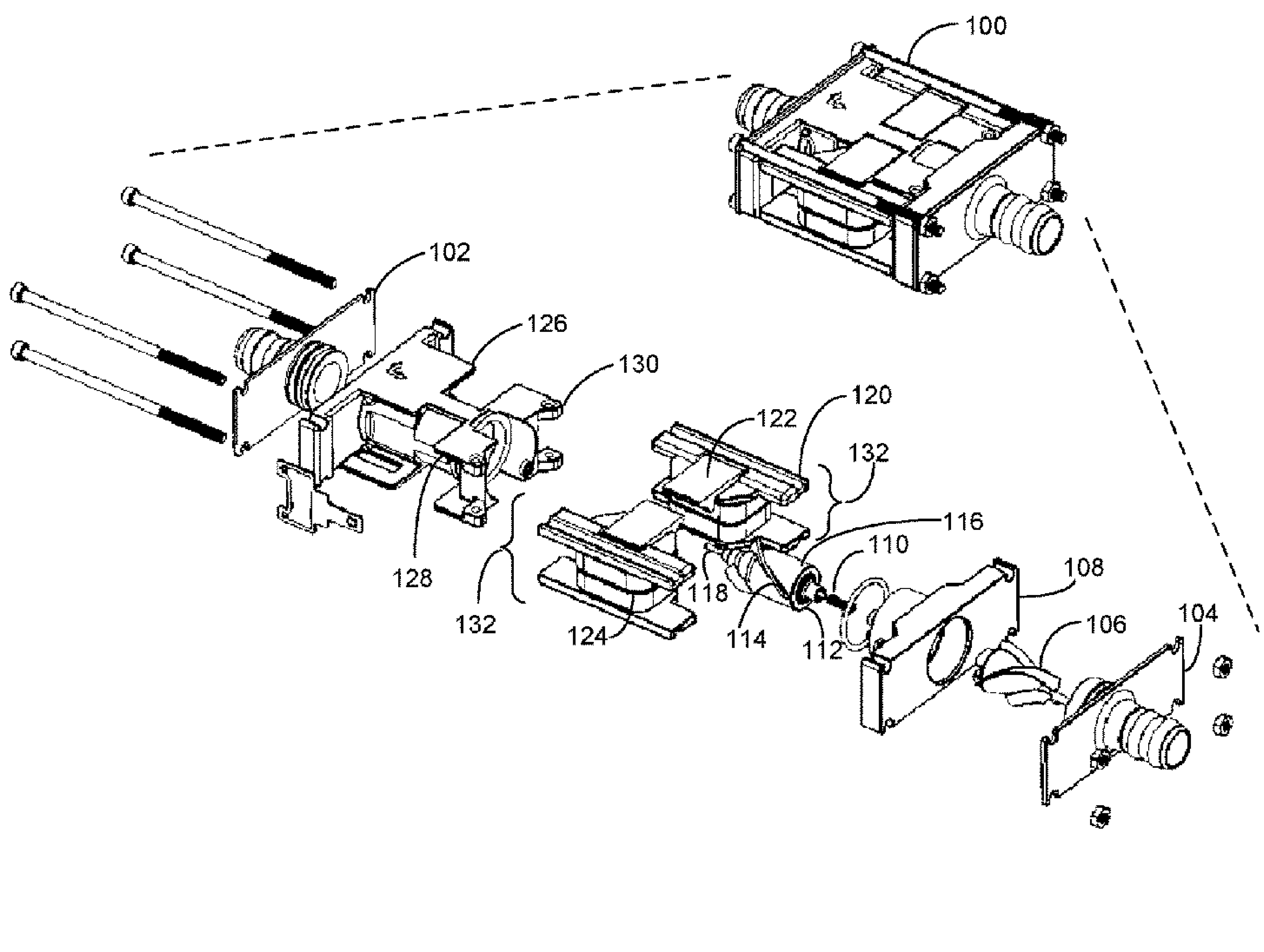
(57) **ABSTRACT**

One aspect described in this application provides an apparatus that includes an external tray hose with an integrated booster pump for cooling a computing device. The booster pump can boost fluid flow and fluid pressure of coolant fluid pumped toward the computing device on a server tray. The booster pump includes a stator mounted around a booster pump housing with a bore. The stator includes one or more C-shaped lamination stacks for supporting coil windings. Energized coil windings generate a varying magnetic field for rotating an impeller within a housing bore to pump fluid along the housing bore of the booster pump. The apparatus includes a monitor module to monitor a set of sensors to obtain information about one or more of fluid temperature, fluid pressure, and device temperature; and a control module to adjust performance of the booster pump based on the information obtained from the set of sensors.

14 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

F04D 29/52	(2006.01)
F04D 13/12	(2006.01)
F04D 15/00	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,439,620	B1	8/2002	Guest	
6,962,625	B2	11/2005	Bredesen	
6,988,518	B2	1/2006	Rackers	
6,989,990	B2	1/2006	Malone et al.	
7,020,997	B1	4/2006	Thomas	
7,354,307	B2	4/2008	Chee et al.	
7,635,010	B1	12/2009	Manno et al.	
7,811,278	B2	10/2010	Knipple et al.	
10,111,364	B2	10/2018	Arvelo et al.	
10,143,111	B2 *	11/2018	Slaby	F04B 51/00
2013/0312846	A1	11/2013	Eriksen et al.	
2014/0132106	A1 *	5/2014	Horst	H02K 21/185 310/216.001
2015/0135588	A1	5/2015	Gergek	
2017/0064911	A1	3/2017	Trujillo	
2020/0163257	A1 *	5/2020	Franz	H05K 7/20836
2020/0182251	A1 *	6/2020	Cader	F04D 29/406

FOREIGN PATENT DOCUMENTS

WO	2019/053439	A2	3/2019
WO	2019/071059	A1	4/2019

* cited by examiner

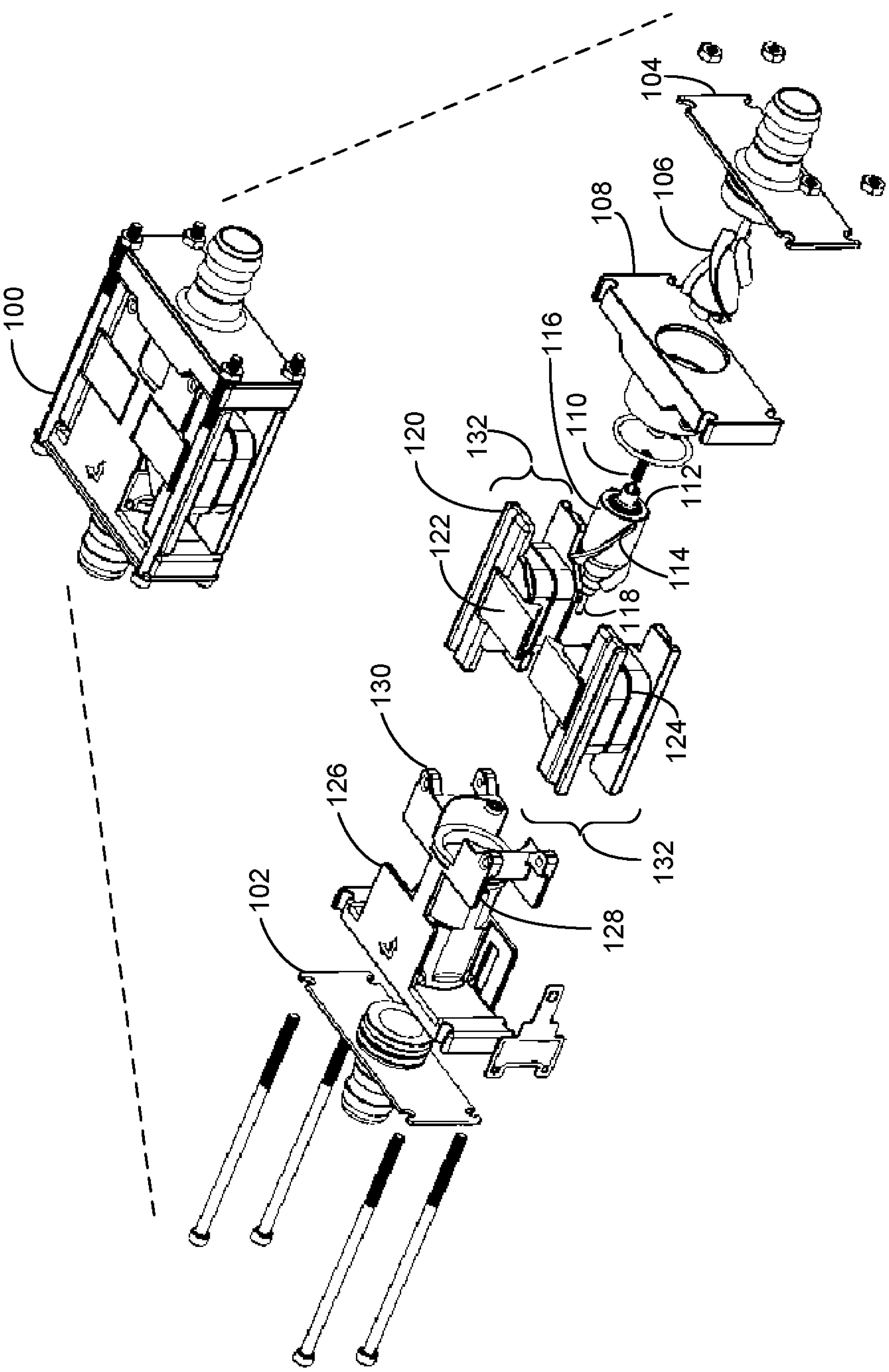
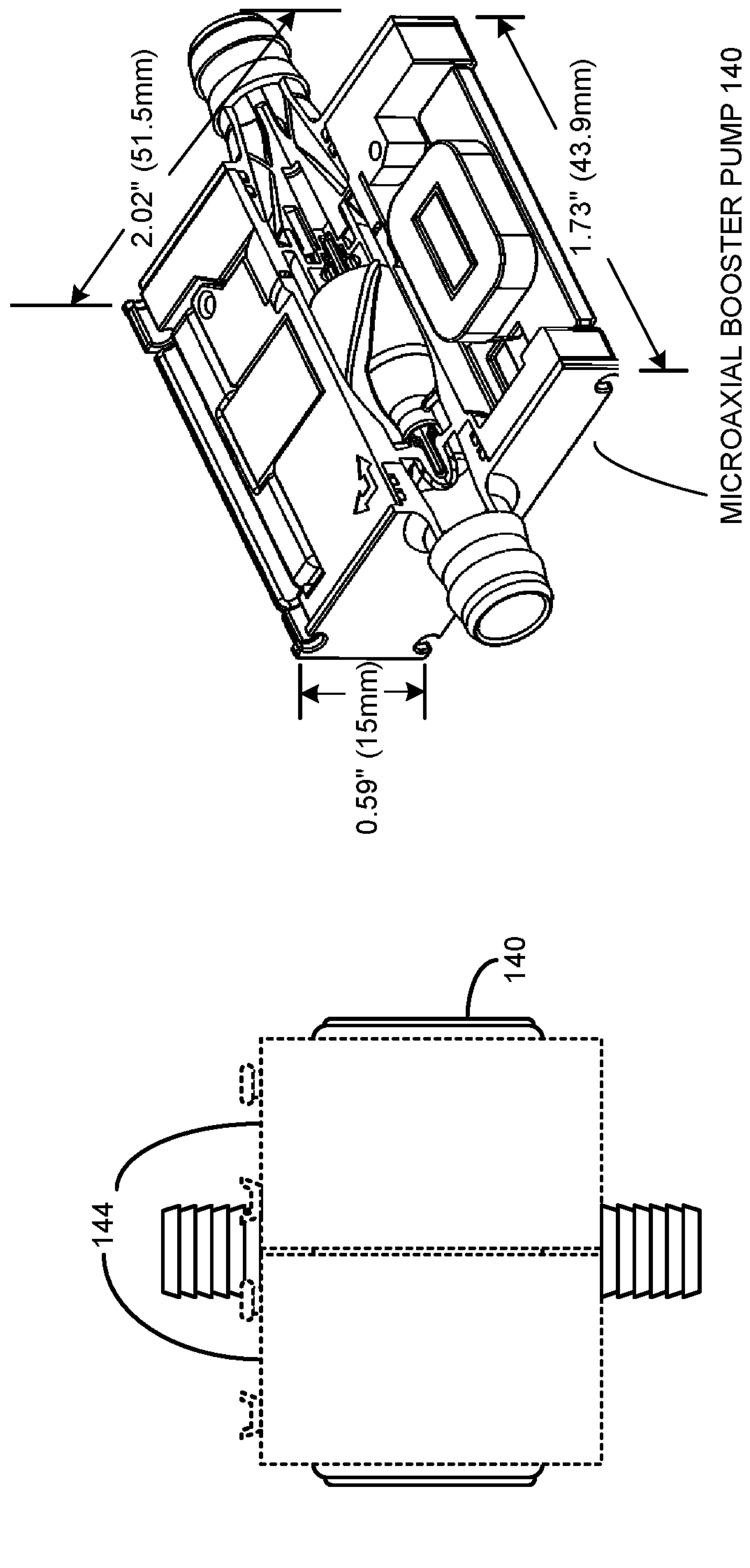

100
104
106
108
116
110
112
114
118
120
122
124
132
130
126
102
128
132

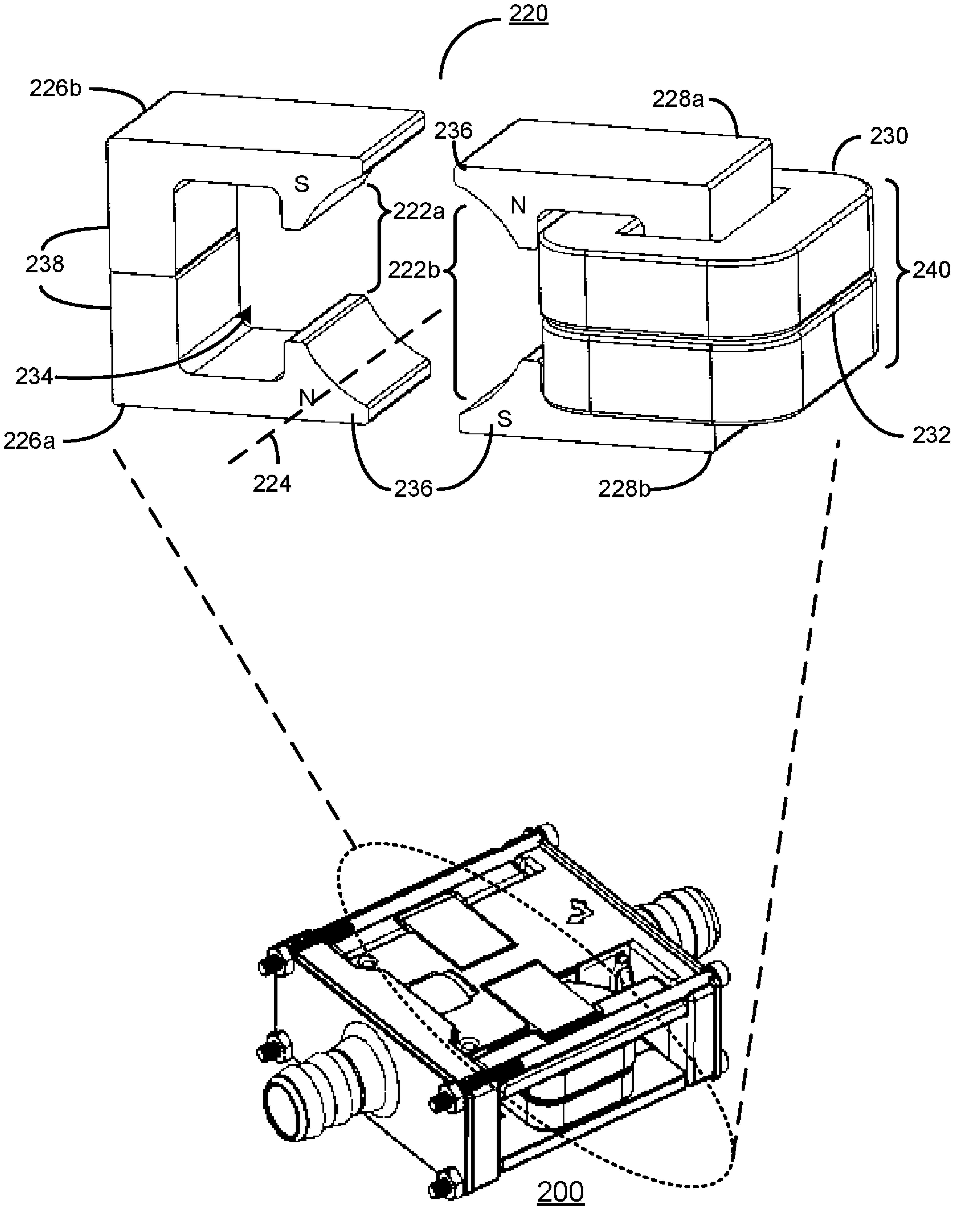
FIG. 1A


2.02" (51.5mm)
1.73" (43.9mm)
0.59" (15mm)
MICROAXIAL BOOSTER PUMP 140
144
140

(b)

(a)

FIG. 1B



220
226b
228a
236
230
S
N
222a
238
222b
240
234
N
S
226a
224
236
228b
232
200

FIG. 2

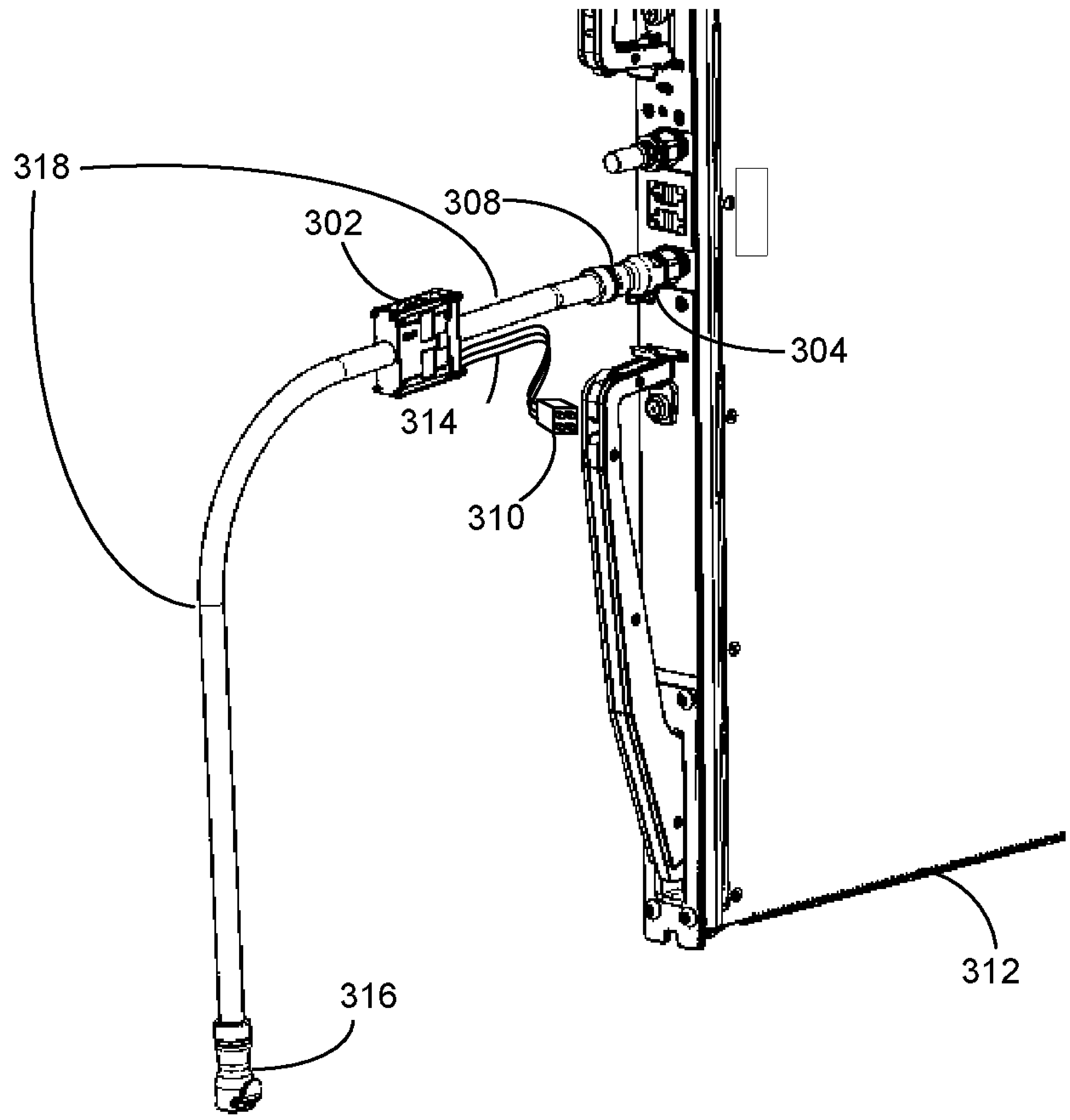


FIG. 3A

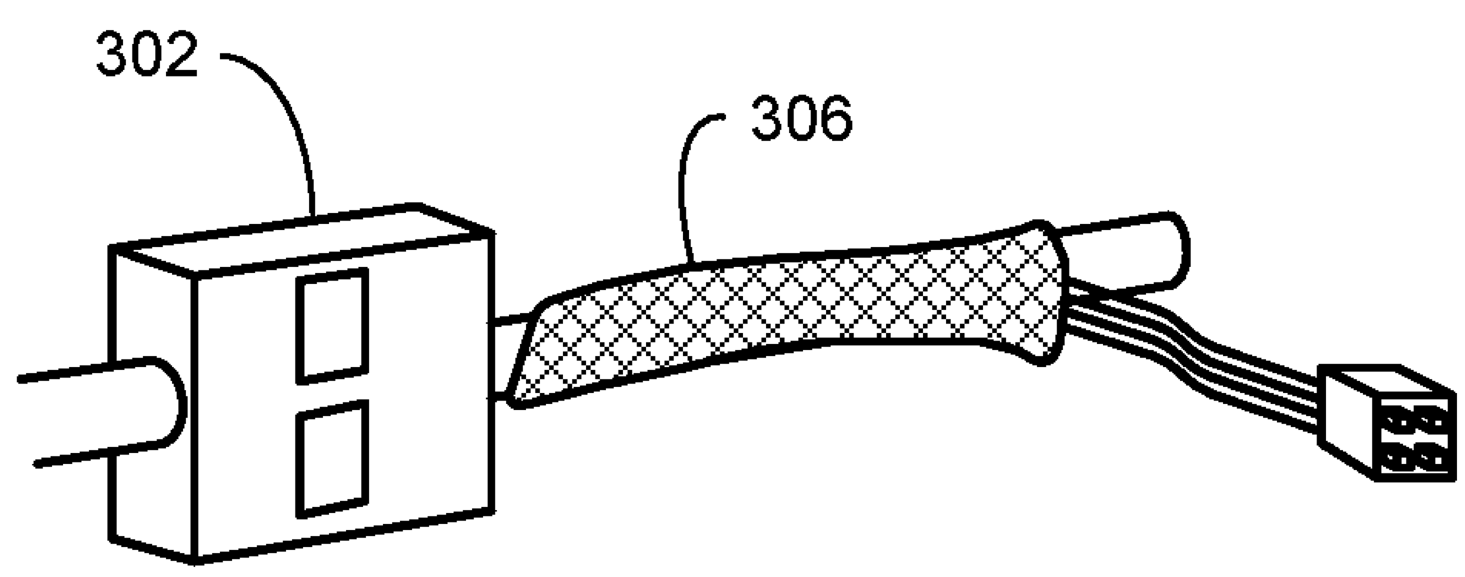


FIG. 3B

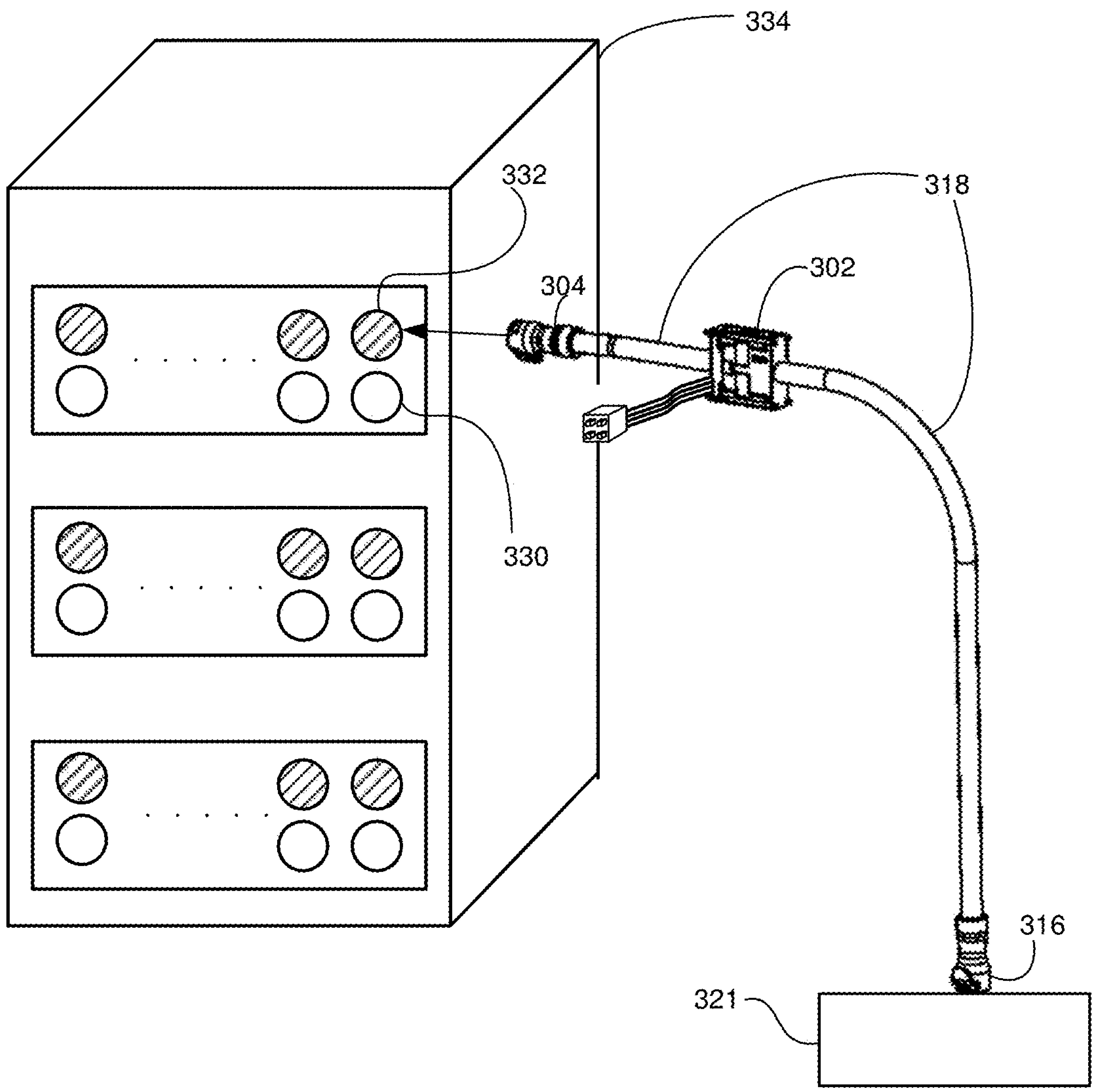


FIG. 3C

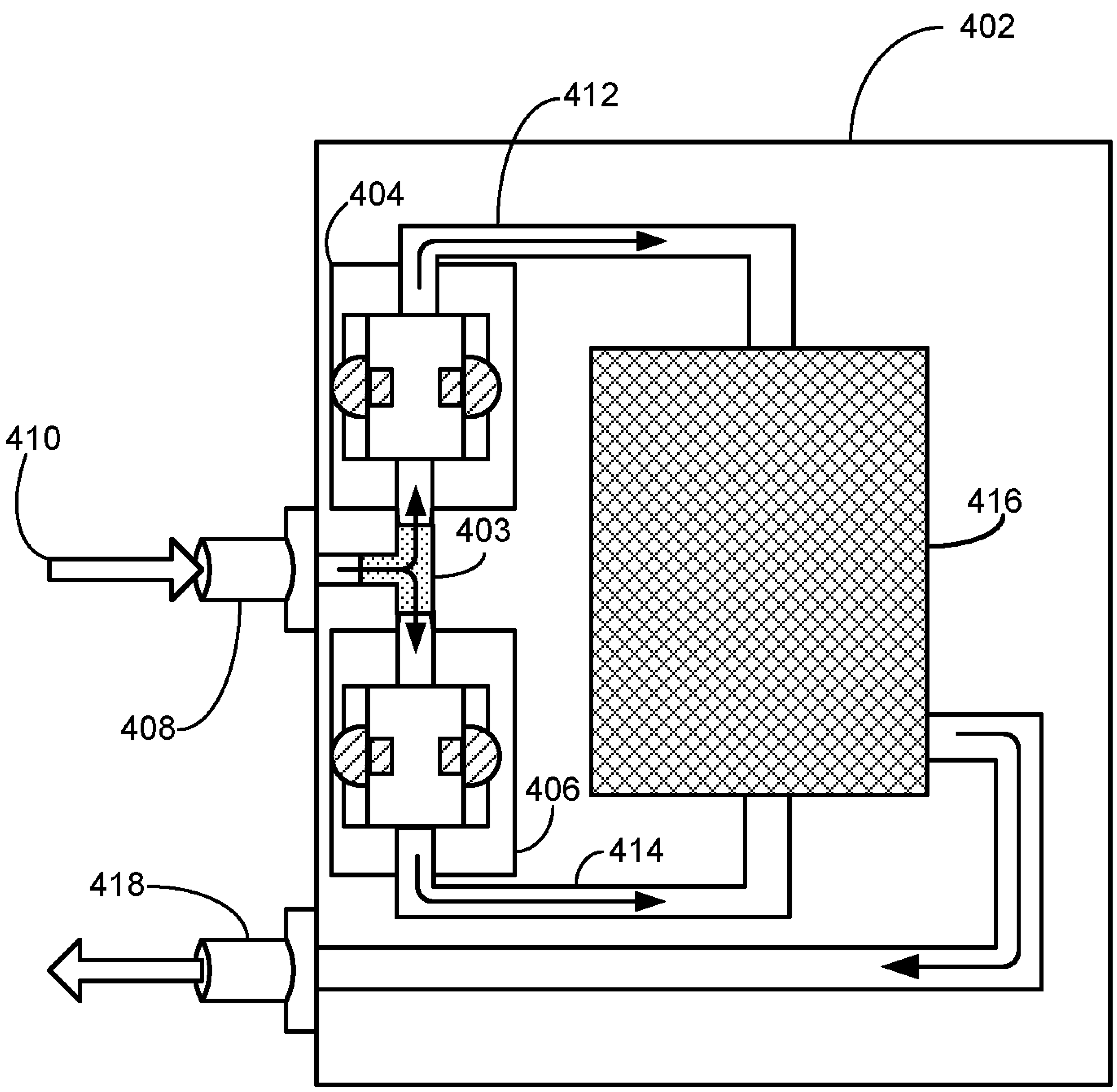


FIG. 4

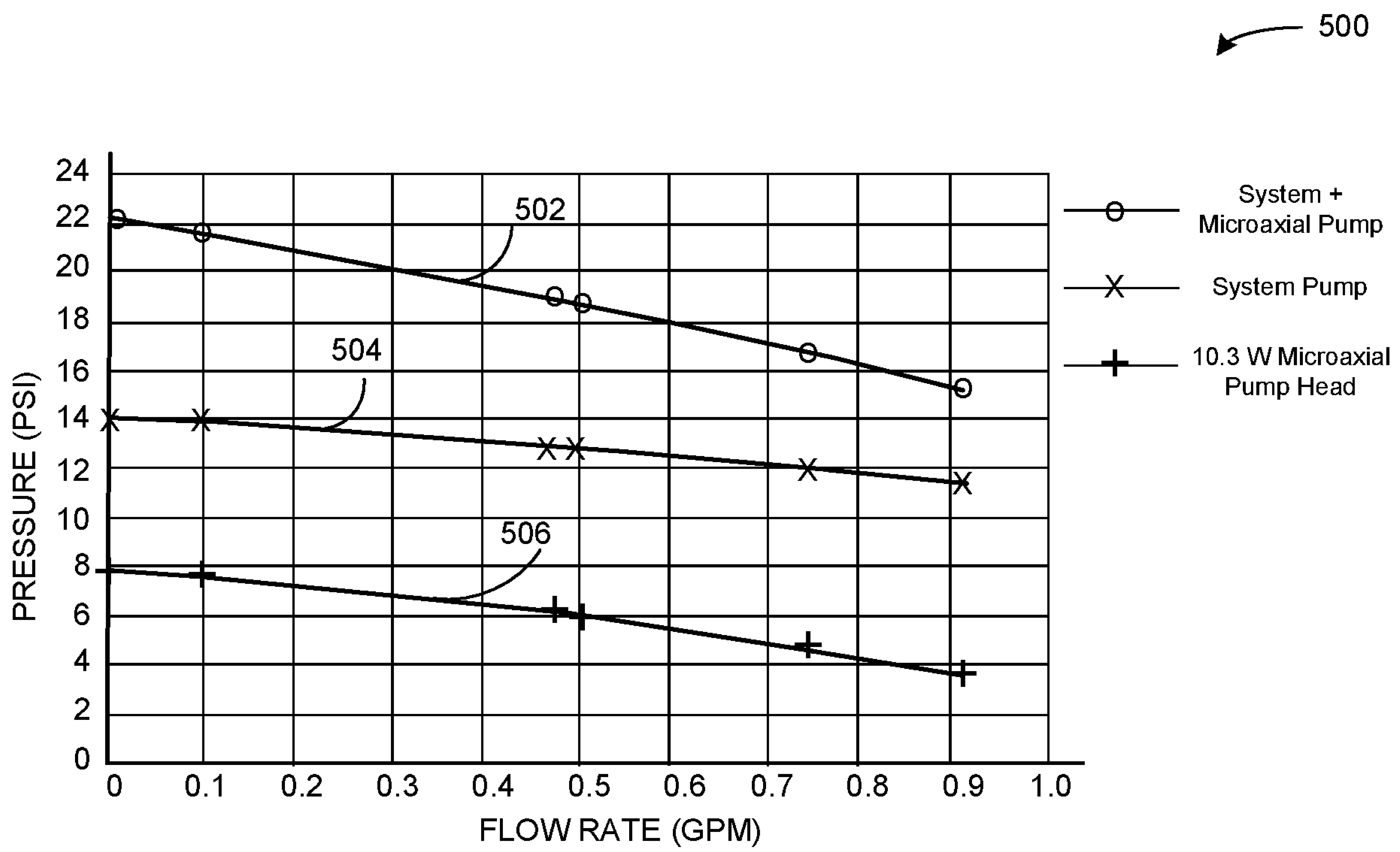

500
502
504
506
PRESSURE (PSI)
FLOW RATE (GPM)
0
2
4
6
8
10
12
14
16
18
20
22
24
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
System + Microaxial Pump
System Pump
10.3 W Microaxial Pump Head

FIG. 5A

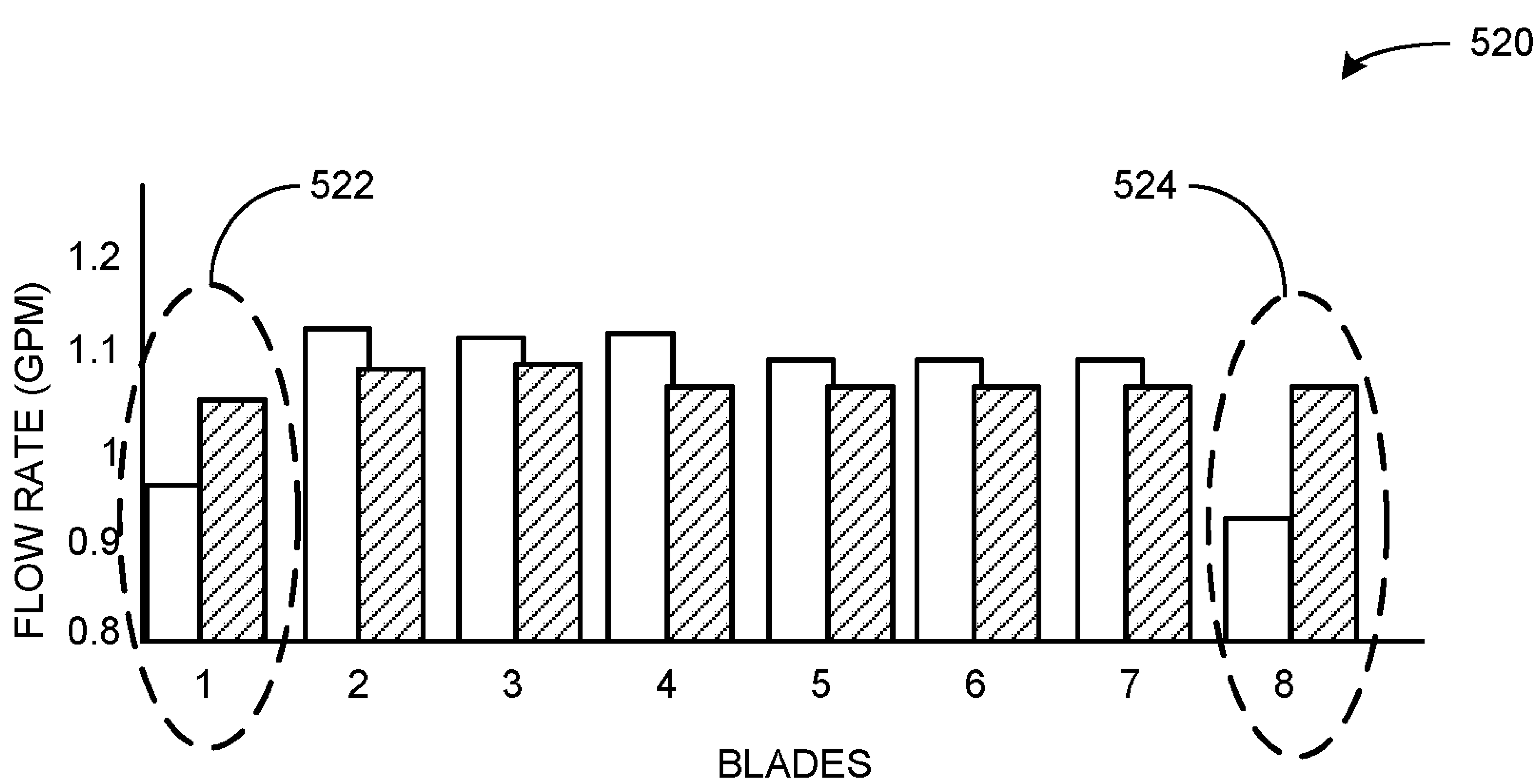

520
522
524
FLOW RATE (GPM)
0.8
0.9
1
1.1
1.2
1
2
3
4
5
6
7
8
BLADES

FIG. 5B

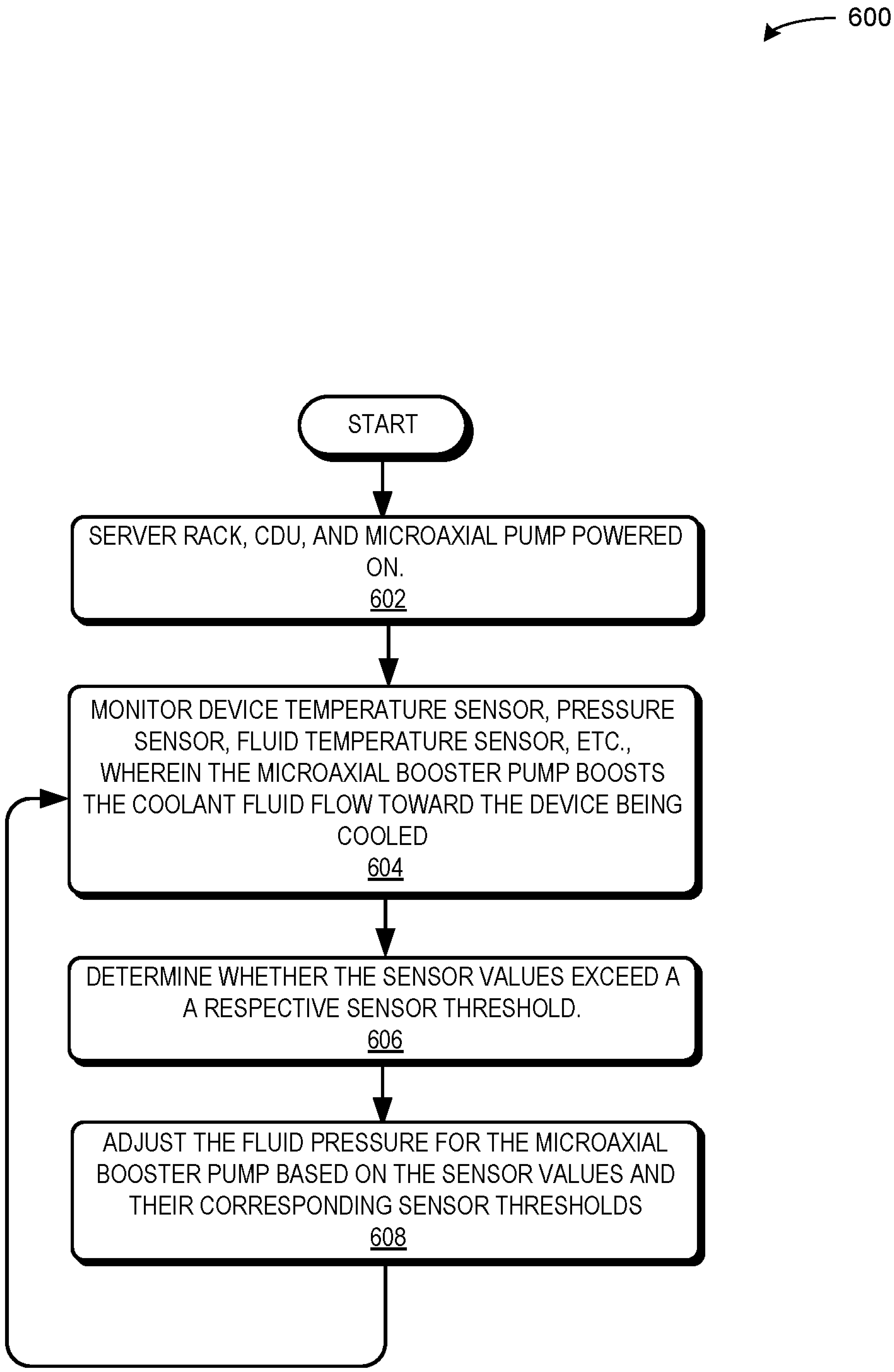

600
START
SERVER RACK, CDU, AND MICROAXIAL PUMP POWERED ON.
602
MONITOR DEVICE TEMPERATURE SENSOR, PRESSURE SENSOR, FLUID TEMPERATURE SENSOR, ETC., WHEREIN THE MICROAXIAL BOOSTER PUMP BOOSTS THE COOLANT FLUID FLOW TOWARD THE DEVICE BEING COOLED
604
DETERMINE WHETHER THE SENSOR VALUES EXCEED A A RESPECTIVE SENSOR THRESHOLD.
606
ADJUST THE FLUID PRESSURE FOR THE MICROAXIAL BOOSTER PUMP BASED ON THE SENSOR VALUES AND THEIR CORRESPONDING SENSOR THRESHOLDS
608

FIG. 6

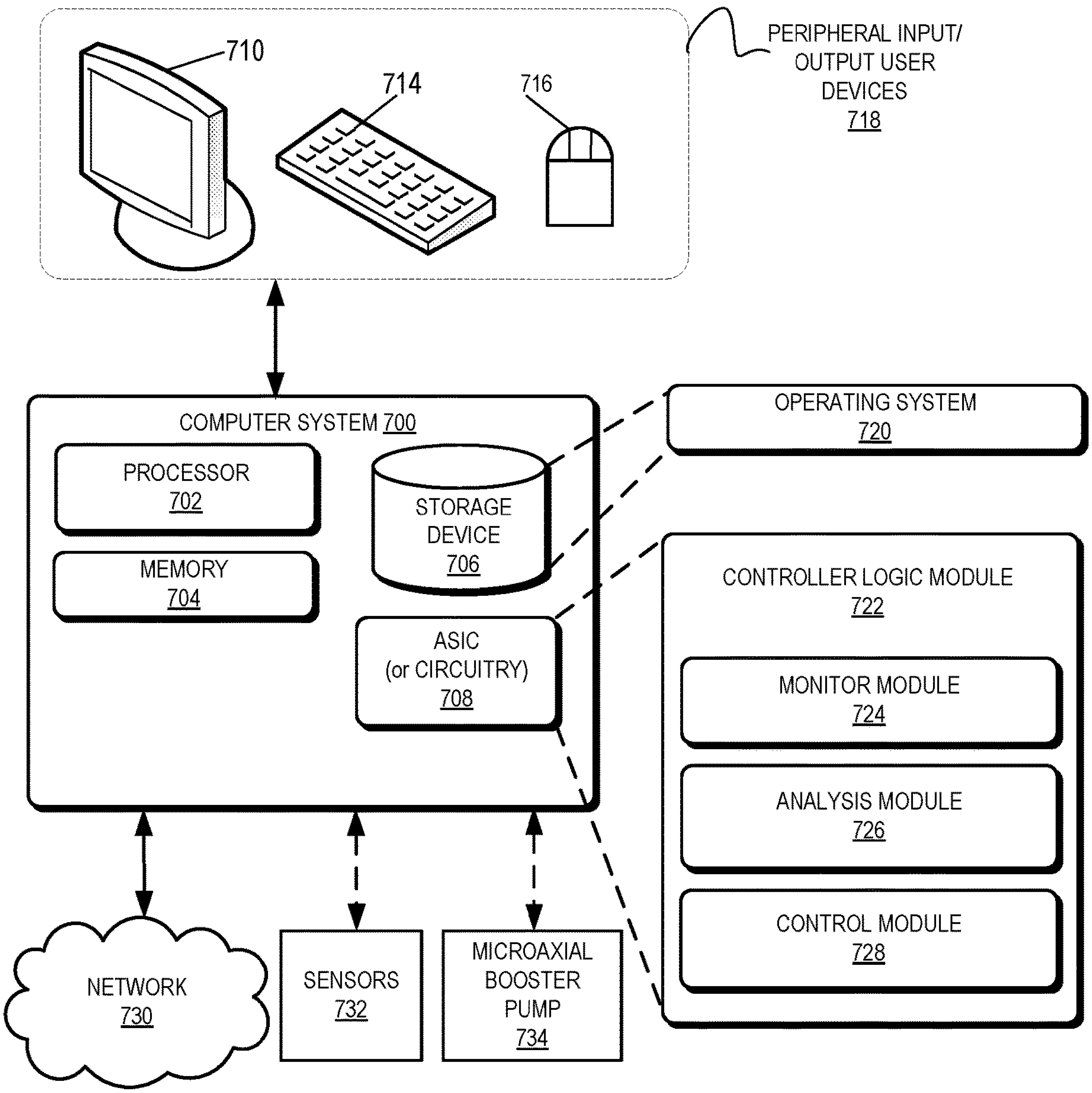

710
714
716
PERIPHERAL INPUT/ OUTPUT USER DEVICES 718
COMPUTER SYSTEM 700
PROCESSOR 702
MEMORY 704
STORAGE DEVICE 706
ASIC (or CIRCUITRY) 708
OPERATING SYSTEM 720
CONTROLLER LOGIC MODULE 722
MONITOR MODULE 724
ANALYSIS MODULE 726
CONTROL MODULE 728
NETWORK 730
SENSORS 732
MICROAXIAL BOOSTER PUMP 734

FIG. 7

EXTERNAL TRAY HOSE WITH INTEGRATED PUMP

RELATED APPLICATIONS

This application is related to U.S. application Ser. No. 16/215,498, entitled "AXIAL FLOW PUMP WITH REDUCED HEIGHT DIMENSION," by inventors John P. Franz and Tahir Cader, filed 10 Dec. 2018; and is further related to U.S. application Ser. No. 16/579,254, entitled "SWIVEL-CAPABLE LOW-PRESSURE-DROP HOSE BARB FITTINGS," by inventors John P. Franz and Tahir Cader, filed 23 Sep. 2019, which are herein incorporated by reference in their entirety.

BACKGROUND

This disclosure is generally related to the field of cooling systems for processing units in a computer system. During operation, the processing units generate heat and when the generated heat exceeds a manufacturer specified normal temperature range, the operation of the computing device (or processing unit) may be impacted. Therefore, to maintain the temperature of the computing device within the normal temperature range, different types of cooling systems are provided to cool the computing device. Some computer systems include a coolant distribution unit (CDU) to deliver coolant fluid to the liquid-cooled computing device, e.g., a central processing unit (CPU), to cool down the computing device, thereby facilitating normal operation of the computing device.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1**A shows an expanded view of an exemplary microaxial booster pump, according to one aspect of the present application.

FIG. **1**B shows approximate dimensions of an exemplary microaxial booster pump, according to one aspect of the present application.

FIG. **2** illustrates a perspective view of a lamination stack of the microaxial pump shown in FIG. **1**A, according to one aspect of the present application.

FIG. **3**A illustrates an exemplary microaxial booster pump integrated into an external tray hose assembly and attached to a server tray, according to one aspect of the present application.

FIG. **3**B illustrates an exemplary microaxial booster pump integrated into an external tray hose assembly with a protective sleeve, according to one aspect of the present application.

FIG. **3**C illustrates an exemplary microaxial booster pump integrated into an external tray hose assembly and connected to a rack of servers, according to one aspect of the present application.

FIG. **4** illustrates an exemplary microaxial booster pump mounted within a server tray, according to one aspect of the present application.

FIG. **5**A shows a graph illustrating fluid pressure versus fluid flow rate curves for a system with and without a microaxial booster pump, according to one aspect of the present application.

FIG. **5**B shows a bar graph to illustrate how the microaxial booster pump can be used to deploy servers in a single chassis with mixed fluid pressure drops, according to one aspect of the present application.

FIG. **6** presents a flowchart illustrating an exemplary process for controlling the fluid flow rate of the microaxial booster pump, according to one aspect of the present application.

FIG. **7** illustrates an exemplary computer system that facilitates controlling of the fluid flow rate of the microaxial booster pump, according to one aspect of the present application.

In the figures, like reference numerals refer to the same figure elements.

DETAILED DESCRIPTION

The following description is presented to enable any person skilled in the art to make and use the examples and is provided in the context of a particular application and its requirements. Various modifications to the disclosed examples will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the present disclosure. Thus, the scope of the present disclosure is not limited to the examples shown but is to be accorded the widest scope consistent with the principles and features disclosed herein.

With the rapid advancement in computer technology and growth in computationally intensive applications, e.g., artificial intelligence (AI) based applications, there has been an increase in the deployment of a mixture of central processing units (CPUs) and Graphics Processing Units (GPUs) in a computer system. GPUs facilitate the computationally intensive workloads involving parallel computing or accelerated computing.

Further, there has been a rapid increase in the amount of power consumed by the CPUs and the GPUs. For example, in some computing systems or servers the power consumption for CPUs can exceed approximately 500 W whereas for GPUs the power consumption can exceed approximately 700 W. In addition, since the high bandwidth memory (HBM) systems are co-packaged with the CPU and the GPU die, the amount of heat generated can result in temperatures approaching 50 degrees Celsius and can easily exceed the manufacturers' specified device-case temperatures (that are often below 60 degrees Celsius). To prevent the damage of computing devices at temperatures approaching or exceeding the device-case temperatures several cooling mechanisms are applied, e.g., one or more air-cooled mechanisms and one or more liquid-cooled mechanisms. Several device manufacturers often support liquid-cooled cold plate solutions for their devices. One of the drawbacks with cold plate technologies is that they are generally fin-based and evolve slowly when compared to the growth in computer technology. Therefore, cooling solution vendors improve the cooling effect induced on the computing devices by forcing more liquid, i.e., by increasing the liquid flow rates, through the cold plate to satisfy the device specifications.

Coolant distribution units (CDUs) are used to deliver coolant fluid to liquid-cooled servers and traditionally they can support four cabinets; and the cabinet to CDU ratio is typically 4:1 (one cabinet can be equivalent to two server racks). Increasing the liquid flow rates for a computing device can result in an increase in the overall flow rates for servers, e.g., servers deployed for high performance computing (HPC) systems, which can reduce the cabinet to CDU ratio down to 3:1 or further to 2:1. A lower cabinet to CDU ratio indicates that one CDU can support a fewer number of cabinets and additional CDUs may have to be deployed which can increase the cost of liquid-cooled solutions.

Further, deployment of additional CDUs can result in more floor space usage, an increase in warranty costs for the customer, an increase in maintenance costs, etc.

Furthermore, with the transition to increased heterogeneous computing, in which CPU and GPU servers can be mixed in a single chassis, the fluid flow rates, and fluid pressures can drop differently on different servers. Existing liquid-cooled solutions can be poorly suited for such heterogeneous computing systems. This is because the CDU might unevenly distribute the fluid flow across the different servers. For example, a blade with high impedance can result in higher pressure drops and fluid flow rates when compared to other servers in a server chassis.

Some of the aspects in this application solve the above-mentioned problems by applying an apparatus and mechanism to increase the fluid flow rates without reducing the cabinet to CDU ratio. A small microaxial booster pump can be integrated into an external hose assembly that connects to each tray to a rack fluid distribution system. The microaxial booster pump can boost the flow and pressure on certain trays that desire performance improvement. Further, a hose-integrated pump can be easily serviced and replaced without the need to perform a time-consuming service event with the removal of the server from the cabinet. The microaxial booster pump can be optionally mounted on a server tray. Due to its small size, the microaxial booster pump occupies less space and can be deployed in a number of space constrained applications. Both the implementations, i.e., a booster pump integrated into the external tray hose and the booster pump mounted within the server tray metal sheet volume, can boost the fluid flow rate and fluid pressure on certain trays that desire enhanced performance. The microaxial booster pump can allow the mixing of different trays with different pressure drops (or impedances) in a given server chassis, and at a rack-scale. The system can hence even-out the fluid flow distribution across the different servers in the given chassis. In other words, the system can ensure a certain fluid flow rate for a server so that the fluid flow rate matches with fluid flow rates associated with other servers in the server chassis.

The terms "liquid" and "fluid" are used interchangeably in this application.

The term "server" refers to a high-density server computer whose design has been optimized to reduce physical size and power consumption.

The terms "rack" or "server rack" refer to a cabinet like structure that can house IT equipment.

The terms "chassis" or "server chassis" can refer to a metal frame within which one or more servers can be assembled.

Microaxial Booster Pump

FIG. **1**A shows an expanded view of an exemplary microaxial booster pump, according to one aspect of the present application. Note that the microaxial booster pump described below is for illustration purposes only. Different types of microaxial pumps can be used in the present inventive system. A microaxial booster pump **100** as illustrated in FIG. **1**A can be connected to a cooling loop via hose barb fittings. Microaxial booster pump **100** can include an inlet barb fitting **102** which can be attached to a hose for allowing coolant fluid to flow towards the pump. Microaxial pump **100** can also include an outlet barb fitting **104** which can be attached to another hose to allow coolant fluid to flow out of the pump. Inlet barb fitting **102** and outlet barb fitting **104** can provide enlarged coolant flow passages, allow use of hoses with increased diameters, reduce pressure drops and erosion (with use of plastic hose barb fittings), and facilitate greater efficiency and longevity in liquid-cooling systems. Microaxial booster pump **100** can further include an outlet barb insert **106**, a bore **128**, an inlet housing structure **130**, and an outlet housing structure **108**. Inlet housing structure **130** and outlet housing structure **108** when connected together can form a fluid sealed housing with bore **128**. Microaxial booster pump **100** can further include a biasing spring **110**, a cap **112**, a magnet (internal) **114**, an impeller **116**, a shaft **118**, a coil frame **120**, laminations **122**, copper windings **124**, a stator **132**, and a printed circuit assembly (PCA) **126**. The motor control circuit can be positioned on PCA **126** which can be mounted on an inlet or outlet part of pump **100**. PCA **126** may be connected to an overall control system in a number of ways based on the use case or application.

Impeller **116** and magnet **114** may be separate components fitted together so that they are rotationally fixed with respect to each other about a longitudinal axis along shaft **118**. Impeller **116** can be mounted on shaft **118** for enhanced support and balancing, for higher speed performance and longer life with less vibration. Impeller **116** can optionally be of a plastic or metallic material. Stator **132** can be mounted around the pump housing and can include a coil arrangement, i.e., coil windings **124**, that can be adapted to impart varying magnetic field through the housing (inlet housing structure **130** and outlet housing structure **108**, for example) to drive magnet **114** about the longitudinal axis. Stator **132** can include laminations **122** which can have C-shaped stacks, e.g., two stacks, and each lamination stack may have a coil winding **124** in coil frame **120**. Such an arrangement can define two poles for each lamination stack, with one at each end of the C-shaped section.

Coil winding **124** may be wound around a middle section of the C-shaped lamination stack. The pole teeth of each lamination stack may be positioned at spaced or adjacent sectors of the bore and provide magnetic poles of opposite sense with respect to one another. At least four magnetic poles may thereby be arranged around the bore. Nevertheless, the bulk of each lamination stack and their associated coil windings **124** may be positioned on either side of the bore so that the housing around the bore accounts for most of a height dimension of the pump. This arrangement allows the flow cross section of the pump to be increased while the height dimension of the pump.

Furthermore, coil windings **124** can be elongated and the axis of coil windings **124** can define axis planes parallel to a longitudinal axis (please refer to item **224** shown in FIG. **2**). The elongate nature of coil windings **124** can facilitate a larger magnetic linkage and the power of pump can be increased without increasing the height of the pump. FIG. **1**B shows approximate dimensions of an exemplary microaxial booster pump, according to one aspect of the present application. In the example shown in FIG. **1**B, FIG. **1**B (a) presents a top view of microaxial booster pump **140** compared with the size of two 9V batteries **144** placed side-by-side. FIG. **1**B (b) shows a perspective view of microaxial booster pump **140** with approximate dimensions. In this example, microaxial booster pump **140** can be approximately 15 mm in height, 44 mm in length (along the direction of fluid flow), and 52 mm in width. The compact nature of the microaxial booster pump can facilitate its use in a number of different space-constrained applications, thereby increasing the number of use cases or applications for the microaxial booster pump. Note that the dimensions presented in FIG. **1**B are for illustration purposes only. Microaxial pumps of other dimensions can also be used.

FIG. **2** illustrates a perspective view of a lamination stack of the microaxial booster pump shown in FIG. **1**A, according to one aspect of the present application. As illustrated in FIG. **2**, a microaxial booster pump **200** can include a stator **220**. In one embodiment, stator **220** can be outside a housing structure and include a coil arrangement to produce a variable magnetic field through the bore to interact with a magnet. Further, the variable magnetic field can drive the magnet and the impeller to rotate about a longitudinal axis **224**, which in turn can drive the fluid along the housing bore (see bore **128** shown in FIG. **1**A). Stator **220** can include two lamination stacks, i.e., **222***a* and **222***b*, that can be C-shaped and perpendicular to longitudinal axis **224** of microaxial booster pump **200**. Longitudinal axis **224** can also represent a rotation axis of the magnet sleeve impeller assembly (see impeller **116** shown in FIG. **1**A). Lamination stacks **222***a* and **222***b* can define the stator of a substantially cuboid form, of which the width can be greater than the height. Each lamination stack (**222***a* and **222***b*) can further include two parts **226***a*-**226***b* and **228***a*-**228***b*. Each plate of each lamination stack part (**226***a*-**226***b*, **228***a*-**228***b*) can be substantially identical, resulting in substantially identical lamination stack parts (**226***a*-**226***b*, **228***a*-**228***b*) and substantially identical lamination stacks **222***a*-**222***b*. Lamination stack parts (**226***a*-**226***b*, **228***a*-**228***b*) can be fitted together with mating projections **238** around which coil windings **232** are placed. Such an arrangement can direct coil generated magnetic flux to pole tooth region **236**.

When lamination stack parts (**226***a*-**226***b*, **228***a*-**228***b*) are assembled as shown in FIG. **2**, they can support a coil arrangement **230** which can include one or more coil windings **232**. Each coil winding **232** can be optionally mounted on a bobbin (not shown in FIG. **2**) and/or wrapped to retain the windings in position. Coil windings on lamination stack **222***a* are not shown in FIG. **2** to illustrate a cutout **234** in the lamination plate that can serve to receive and accommodate windings in each lamination stack part (**226***a*-**226***b*, **228***a*-**228***b*). Coil winding **232** may be wound around a waist or middle section of the C-shaped lamination stack (**222***a* and **222***b*). During operation, electric current can energize each coil winding and the energized coil winding can generate a rotating magnetic field in respective laminations stack part (**226***a*-**226***b*, **228***a*-**228***b*) which may in turn create a magnetic pole at tooth region **236** of each lamination stack. In general, pole tooth region **236** can be configured in such a way that the generated magnetic flux can be concentrated toward the cylindrical permanent magnet of the rotor of the pump. In the example illustrated in FIG. **2**, tooth region **236** can have a concave surface facing the rotor, thereby increasing the efficiency of the pump. The rotating magnetic field, which can be generated by alternating current in the coils, can cause the cylindrical permanent magnet to rotate around longitudinal axis **224**. The impeller, which is fixed to the permanent magnet, can be rotated and drive fluid along the housing bore.

A coil region **240** of a lamination stack part (**226***a*-**226***b*, **228***a*-**228***b*) can be the area of the lamination perpendicular to longitudinal axis **224**. Coil region **240** can be occupied by coil winding **232** in its passage through and around the lamination.

Further, projections **238** of each lamination stack part (**226***a*-**226***b*, **228***a*-**228***b*) can penetrate each coil winding **232** and link the magnetic flux generated by coils **232** with tooth regions **236**. Note that projections **238** illustrated in FIG. **2** has a cuboid shape. Other shapes, such as cylindrical, or a shape with an oval cross-section, can also be used. The polarity (N/S) of each pole tooth **236** can be alternated by alternating the direction of current in each winding **232**. The magnetic field that coils **232** generate in lamination stack **220** may interact with the magnetic field of a permanent magnet sleeve to drive the magnet sleeve and connected impeller sleeves. As a result, the impeller can rotate about longitudinal axis **224** and thereby drive fluid in the bore of the impeller sleeves from fluid inlet **102** to fluid outlet **104** (shown in FIG. **1**A) of the microaxial booster pump. The magnetic poles of one lamination stack **222***a* can be arranged opposite corresponding magnetic poles of lamination stack **222***b*. Each magnetic circuit can be driven by respective coils **232** around the waist of C-shaped lamination stacks (**222***a* and **222***b*) that are defined by projections **238**.

Control of the alternating current in the coils **232** may be affected through a control board (PCA) **234** (PCA **126** shown in FIG. **1**A). The speed of rotation can be adjusted by changing the voltage applied across coils **232** and the frequency of alternation. For example, the microaxial booster pump can be configured to operate with a pressure of 2 pounds per square inch differential (psid) and with rotation speeds in the range 20 to 30000 rpm. When pulse width modulation (PWM) is used to control the pump, the PWM frequency is typically above 50 Khz to ensure that a sufficient number of AC cycles take place within one commutation cycle in order for the current to be regulated without the current reaching a steady (DC) state. In addition, the DC voltage supply to the pump can have a range of 0-12V. Other voltage ranges and frequencies can also be used. Parameters which drive the control may be determined in different ways depending on the application, e.g., fluid temperature, power consumed and/or apparatus (computing device) generated heat that is cooled by the coolant pumped from microaxial booster pump.

Some of the aspects of this application address one or more use cases of the microaxial pump in a booster fashion to address the disparities in server or compute tray pressure drops. Typically, a cabinet or a rack can include one or more servers (or compute trays); and one or more cabinets can represent a cluster. In a deployed cluster, the CDU may have to satisfy the servers with the highest pressure drop in a 4-cabinet cluster that the CDU is supporting, i.e., a 4:1 cabinet to CDU ratio. When the CDU encounters an increase in pressure drop, its ability to provide more coolant flow decreases towards the computing device being cooled, thereby reducing the number of cabinets that the CDU can support. Typically, the highest pressure-drop servers represent a small percentage of the servers deployed in a given cabinet or cluster. When a CDU can support a fewer number of cabinets, e.g., 2:1 cabinet to CDU ratio instead of 4:1, more CDUs may have to be deployed to support the given number of cabinets, which can increase the costs, and may also result in occupying more floor space, increased maintenance, and increased warranty costs for the customer, etc.

Current systems are designed to use treated water as the coolant. A number of instances of biological growth for systems using treated water is forcing the transition to a propylene glycol/water-based (PGW-based) chemistry to prevent biological growth in the system while providing freeze protection during shipping. The change to a PGW mixture incurs a double impact on the cooling system. First, the fluid has a higher viscosity which reduces the flow output of the CDU. Second, the poorer thermophysical properties of the PGW (relative to treated water) have a negative impact on thermal performance by reducing heat transfer, which forces a higher flow rate for the trays to achieve the desired thermal performance. In one aspect of this application, the increase in performance provided by the microaxial booster pump can allow systems to be converted from treated water-based to PGW-based without compromising the cooling performance,

With the progression to more heterogeneous computing solutions, the current systems encounter additional challenges. For example, recent developments in computer technology and the demand for fast computing has resulted in deployment of servers that deploy a combination of high-power CPUs, GPUs, Application Specific Integrated Circuits (ASICs), and switch chips. Some of these servers may include a high-density design with high power consumption which can result in a high impedance and may demand higher flow rates of the cooling fluid. The pressure drop across such high impedance servers can be about one-and-a-half times (or 1.5 times) the pressure drop of the bulk of the servers in a cluster. Without flow control at the individual server level, the CDUs are forced to satisfy the worst-case server flow, which means that the bulk of the servers in the cluster will be overprovisioned. Such uneven distribution of fluid flow can result in improper cooling of the computing devices.

Often, the above-mentioned problems are addressed by deploying more or larger CDUs, greater flow rates, and/or lower coolant temperatures. With regards to the IT rack to CDU ratio, the current systems may either alter the ratio of IT racks to each CDU by deploying fewer IT racks per CDU or add additional CDUs for a given number of racks. In the case of mismatched servers, a common solution is to raise the impedance of the available servers to match the worst-case server impedance in a chassis. For example, when a chassis includes a mixture of mismatched servers, i.e., CPU and GPU servers, some of the CPU servers may be removed and replaced with dummy servers to match with the impedance of the high impedance GPU servers. This can result in inefficient use of server slots and an increase in the cost of the IT equipment.

In other words, different trays in a server rack can have varying pressure drops and flow targets that can be difficult for row level CDUs to accommodate without egregious waste, i.e., satisfying the worst-case tray (even for a single tray in a chassis), while simultaneously overprovisioning trays whose performance criteria are already satisfied. Adding booster pumps internal to the server-tray sheet-metal volume (the space within the metal enclosure of a server tray) can be difficult and unattractive due to the lack of space and the size constraints of the existing pumps. Further, in the event of a failure, the repairing and/or replacing time can interfere with the services provides by the IT equipment.

Some of the aspects described in this application address the problems associated with pressure drops across high impedance servers, by integrating a small pump within an external hose assembly that connects each server tray to the rack fluid distribution system. Therefore, deploying a microaxial booster pump for each of the high pressure drop servers or server trays can boost the flow and pressure on those trays that desire the additional performance. In other words, by using such microaxial pumps which are positioned along the coolant supply line to individual servers or trays, the system can facilitate much finer-granularity control of the supply of cooling capacity on a per-server or per-tray basis. Further, to simplify deployment of the booster pump, one aspect of this application may incorporate the pump into a hot-swappable tube with either self-sealing fluid quick disconnects on each end; a valved connection; or a mechanism that can reduce or eliminate fluid loss during a servicing event. This configuration allows for easy access to the pumps and hence lowers maintenance costs. Furthermore, placing the microaxial booster pump on an external hose can preserve space in the server tray and can reduce the risk of a leaky pump within the server tray.

In addition, the use of in-line booster pumps can facilitate mixing of server trays with different pressure drops (or impedances) in a given chassis and at the rack-scale. Therefore, the deployment of microaxial booster pumps can satisfy the increasing demand of customers for a transition to heterogeneous computing that includes a combination of CPU and GPU servers in a server chassis.

In one aspect, the microaxial booster pump can serve as a booster pump to a CDU pump. Furthermore, due to their small size, e.g., approximately the size of two 9V batteries placed side-by-side, the microaxial booster pumps can have a wide variety of space constrained applications.

FIG. **3**A illustrates the microaxial booster pump integrated into an external tray hose assembly and attached to a server tray, according to one aspect of the present application. In the example shown in FIG. **3**A, a hot-swappable microaxial booster pump **302** is coupled to a plug **308** attached to a server residing in a server tray **312**. Booster pump **302** can be powered via a connector **310** that plugs into the server, server tray **312**, or another location in server rack, e.g., a rack manifold, or another power source designed to provide power and control for booster pump **302**. External tray hose **318** can include a first fluid coupler **304** that can be plugged into the front of the server along with booster pump cable connections. The other end of external tray hose **318** can include a connection or a second fluid coupler **316** that can be attached to a fluid supply channel **321**, e.g., a rack manifold.

Connector **310** can couple to the front of server tray to receive power and control signal from a power and control source. Alternatively, the booster pump wire connections with connector **310** can be at the rack manifold when the rack has a manifold integrated to control each booster pump. A variety of traditional connections are supported which can include a power connection, ground connection, tachometer, Pulse Width Modulation (PWM) module, etc.

External tray hose **318**, which can be made of flexible tubing, can have an outside diameter of approximately half an inch. Other host sizes can also be used. A first fluid coupler **304** can be connected at the front of the server and second fluid coupler **316** can be connected to a fluid supply channel **321**, e.g., a rack manifold. FIG. **3**B illustrates how wirings **314** can be in a protective sleeve **306** that can be joined and secured to the hose to prevent damage. In one embodiment, protective sleeve **306** can be a mesh tube or a heat-shrink tube. Other materials can also be used.

FIG. **3**C illustrates the microaxial booster pump integrated into an external tray hose assembly and connected to a rack of servers, according to one aspect of the present application. In this example, external tray hose assembly (jointly **318**, **304**, **316**) can be coupled to a rack of servers **334** with hose connections. In general, a server in rack **334** can have two hose connections, i.e., a supply coupler **332** and a return coupler **330**. Fluid coupler **304** can be coupled to supply coupler **332** to supply fluid into the fluid network for cooling a computing device on the server tray within server rack **334**.

FIG. **4** illustrates a microaxial booster pump mounted within a server tray, according to one aspect of the present application. The example shown in FIG. **4**, depicts another use case for the microaxial booster pump. The booster pump can be mounted within a server tray **402**, which means that the booster pump is mounted internal to server tray **402**. The booster pump occupies a small footprint within server tray **402** and can provide the desired flow rate to the high impedance server. For example, the microaxial booster pump can occupy approximately 2.09 in^3 and can provide a power density (i.e., pump power consumption divided by pump volume) of approximately 0.697 W/in^3, Booster pump can support both an open-loop liquid-cooled solution and/or a closed loop liquid-cooled solution. Furthermore, the compact nature of the booster pump can facilitate its use in a space-constrained environment. In other words, the microaxial booster pump can optionally be mounted internal to server tray.

In one example, two or more microaxial booster pumps mounted within the server tray may be coupled in series or in parallel to allow adjustment of pump pressure and/or flow specifications. For example, booster pumps may be arranged in parallel to increase flow rate without increasing pressure drop or the pumps may be operated in series to increase both pressure drop and flow rate. For both series and parallel operations, the pumps may be arranged to rotate their respective impellers in opposite directions to reduce the swirl effects of the flow upstream of the pumps.

In one aspect, a compound pump may be provided, which can include two booster pumps in series, in which the fluid outlet of a first pump is connected to a fluid inlet of a second pump. Such a series connection of two booster pumps can increase the pressure associated with a single pump. The impellers of each pump may be configured to rotate in opposite directions with respect to one another. Such a configuration can enable a downstream impeller to mitigate the rotation of the coolant fluid caused by the upstream impeller, and hence can improve the efficiency of the compound pump. In a further arrangement of pumps, shown in FIG. **4**, fluid inlet of each pump in a compound pump, which includes two pumps **404** and **406** connected in parallel, can be interconnected by a T-coupler **403** and jointly connected to a fluid inlet **408** (with arrow **410** indicating the direction of fluid flow). The fluid outlets of each pump can be connected to two fluid inlets of a server **416**. The outgoing coolant fluid from server **416** can be guided to outlet **418**. In this arrangement, pumps **404** and **406** are connected in parallel and can increase fluid flow rate. Further, such a parallel arrangement can provide parallel fluid flow paths **412** and **414** with a split tubing configuration. The split tubing configuration can facilitate a balanced fluid flow path towards server **416**.

In one aspect, multiple pumps may be packaged in a small form factor (SFF) hard drive enclosure having approximately 15 mm in height. Such a packaging can provide hot swap ability of the pump package. Within the pump packaging, different fittings such as T-couplers can link the pumps to provide parallel or series flow paths, as may be desired for performance and resiliency.

FIG. **5**A shows a graph including fluid pressure versus fluid flow rate curves for a system with and without a microaxial booster pump, according to one aspect of the present application. The performance of the microaxial booster pump in a booster capacity can be measured with an example setup which can include a CDU or helper pump in series with the microaxial booster pump. The role of the helper pump is similar to the role of a CDU in a cluster or a server rack. In the example shown in FIG. **5**A, graph **500** shows a plot of pressure in pounds per square inch (psi) versus flow rate in gallons per minute (gpm). Curve **504** indicates the pressure vs flow rate values when the CDU system is used without the microaxial booster pump and includes just the CDU system pump. Curve **506** indicates the pressure vs flow rate values with a 10.3 W microaxial booster pump, and curve **502** indicates the pressure vs flow rate values when the CDU system includes a microaxial pump as a booster pump. Since the helper pump and the microaxial booster pump are operated in series, their individual heads are additive which is shown in FIG. **5**A, i.e., adding corresponding values of curves **504** and **506** results in curve **502**. The example shown in FIG. **5**A indicates that the microaxial booster pump can be effectively applied as a booster pump in a CDU system.

In one example use case, the microaxial booster pump can be used in a stand-alone rack that can include two chassis (e.g., with eight servers per chassis), an in-rack CDU, rack manifolds (which comprise fluid supply channels and/or fluid exhaust channels) for fluid distribution, rectifiers for power conversion, switches, etc. The rack can support tubing for supply and exhaust fluid tubes that connect each server to the rack manifolds, which in turn can be connected to the in-rack CDU. Such a fluid distribution arrangement can make it easy to replace a regular fluid supply tube with a hot-swappable pump and tube as shown in FIG. **3**B. When a hot-swappable pump is deployed on each of the available servers in the stand-alone rack or cabinet, the microaxial booster pumps can boost the performance of the CDU pump. Without the microaxial booster pumps running, the flow rate may be low, e.g., approximately 16.7 gpm. With the microaxial booster pumps running at approximately 16,700 rpm, the flow rate can increase, e.g., can be approximately 18 gpm, which results in a boost of about 1.3 gpm for the CDU when compared to a system with no booster pumps. Therefore, the microaxial booster pumps can in effect provide a flow rate boost and lower the system impedance that the CDU pump perceives, e.g., can result in approximately a 7.7% boost in flow rate for the CDU pump.

In another example use case, the microaxial booster pump can be used to deploy servers of mixed pressure drops (impedances) in a single chassis. In general, each slot in a chassis can accommodate one server. For example, a chassis with eight servers can include eight vertical slots with each slot accommodating a single server. In this case, it can be assumed that a server with a pressure drop higher than, e.g., larger by 121%, a nominal server (referred to as a 100% server) can be placed in a leftmost slot 1 and the rightmost slot 8 of a chassis that can house eight servers (or vertical blades). When a microaxial booster pump is included with a high impedance server, e.g., with 121% pressure drop when compared to a nominal server, the booster pump can lower the effective impedance of this server. Therefore, the inclusion of a microaxial booster pump can make a high impedance or a 121% server operate like a nominal or a 100% server by lowering the impedance of the 121% server.

In current systems, it is often desired to deploy servers with slightly higher impedances in a chassis, e.g., heterogeneous computing systems can include CPU and GPU servers mixed in a single chassis. Existing liquid-cooled solutions can be poorly suited to such heterogeneous computing systems. This is because the CDU can unevenly distribute the fluid flow across the different servers and to even out the fluid distribution across the servers the current systems raise the impedance of all the other servers, thereby increasing the impact on the CDU.

FIG. **5**B shows a bar graph to illustrate how the microaxial booster pump can be used to deploy servers in a single chassis with mixed fluid pressure drops, according to one aspect of the present application. For example, assume that a server with a pressure drop of about 150% higher than a nominal server (referred to as a 100% server) is placed in a leftmost slot 1 and the rightmost slot 8 of a chassis that houses eight servers (or vertical blades). In graph **520**, the white bars indicate that without microaxial booster pumps deployed on servers in slot 1 and slot 8 in an eight-server chassis the fluid flow is unevenly distributed across the eight servers in the chassis. The patterned bars (i.e., with slanting line pattern) indicate that by deploying microaxial pumps on servers 1 and 8 the fluid flow distribution across all eight servers in the chassis can be approximately even or balanced. The patterned bars shown in **522** and **524** indicate how the deployment of microaxial booster pump can boost the flow on servers one and eight and reduce the burden on the CDU.

Adding a booster pump to an external hose assembly that is attachable to a server tray and a rack manifold (or a fluid supply channel) via fluid quick disconnects (or a mechanism that can reduce or eliminate fluid loss during a servicing event) can enable increased flow and performance, with no additional space used on a data center floor. Further, the microaxial booster pump can enable mixing of different trays with different pressure drops in a given cassis, and at a rack scale. The increase in performance provided by the booster pump can enable the use of PGW instead of treated water-based fluid. The hose-mounted pump can be easily serviceable and replaceable. Due to the compact nature of the booster pump, it can have varied number of applications in a space constrained environment. For example, the booster pump can be mounted within a server tray metal sheet volume to boost the fluid flow and pressure.

FIG. **6** presents a flowchart illustrating an example process for controlling the fluid flow rate of the microaxial booster pump, according to one aspect of the present application. Referring to flowchart **600** in FIG. **6**, during operation, i.e., when a server rack, CDU, and microaxial booster pump are powered on (operation **602**), the system can monitor a number of servers deployed in the server rack (operation **604**). For example, the server rack can include fluid pressure sensors, device temperature sensors, fluid temperature sensors, etc. The microaxial booster pump can be coupled to a server and provides the coolant fluid thereto. In some situations, the performance of the microaxial booster pump may be controlled to adjust the pressure of the fluid flow that is being driven from the rest of the fluid network. For example, in one aspect a control module which can include dedicated hardware and/or software and reside in a server or the server rack may control the behavior of a respective microaxial booster pump. To control the behavior of the microaxial booster pump, this control module can be configured to monitor a number of sensors.

In one embodiment, the rack level control module may include a monitor circuitry to monitor the pressure flow sensors and may determine whether the sensor values exceed a sensor threshold value (operation **606**). Accordingly, the system can adjust the fluid pressure of the microaxial booster pump (operation **608**). For example, the control module within a rack manager may monitor the pressure flow sensors and analyze their values. Based on the analysis the control module may speed-up or slow down the microaxial booster pump. For example, in a server chassis including eight servers, a server in the first slot can be a high impedance server and a microaxial booster pump connected to this server can boost the fluid flow towards the computing device in the first slot. When the control module at the server level identifies, based on the temperature sensors, that the temperature of a respective server has reached the normal range, the control module may slow down the corresponding microaxial booster pump.

In one aspect, the temperature sensors and the pressure sensors can be located at the server level instead of at the rack level. Correspondingly, the speed of the microaxial booster pump can be controlled by a server level control module based on the device temperature sensors (or pressure sensors) located at the server level.

Computer System

FIG. **7** illustrates an example computer system that facilitates the controlling the fluid flow rate of the microaxial booster pump, according to one aspect of the present application. In this example, computer system **700** can include a processor **702**, a memory **704**, a storage device **706**. Computer system **700** can be coupled to peripheral input/output (I/O) user devices **718**, e.g., a display device **710**, a keyboard **714**, and a pointing device **716**. Storage device **706** can store instructions for an operating system **720**. Computer system **700** can be coupled via one or more network interfaces to a network **730**, a set of sensors **732**, and one or more microaxial booster pumps **734**. Computer system **700** can be at rack level or at a server level in a rack.

Computer system **700** can be equipped with an ASIC or circuitry **708** which can include a controller logic module **722** to perform methods and/or processes described in this disclosure. Controller logic module **722** can implement the process shown in FIG. **6** and can include a monitor module **724**, an analysis module **726**, and a module **728**. Controller logic module **722** can include one or more hardware components and/or software components (i.e., software components that include instructions executable by a processor to perform processes described in this application). A respective module can also include dedicated circuitry.

Monitor module **722** can monitor information or telemetry data corresponding to one or more sensors **732** which can include fluid pressure sensors, device temperature sensors, fluid temperature sensors, etc. Analysis module **726** can analyze the monitored information about sensors **732** and determine whether the sensor values exceed a sensor threshold. Based on this analysis, control module **728** can communicate with microaxial booster pump **734** to control or adjust the speed of microaxial booster pump **734**.

One aspect described in this application can provide an apparatus for cooling a computing device. The apparatus can include a booster pump integrated into an external tray hose, the booster pump to boost fluid flow and fluid pressure of coolant fluid pumped toward a computing device on a server tray. The booster pump includes a stator mounted around booster pump housing with a bore. The stator includes one or more C-shaped lamination stacks for supporting coil windings. Energized coil windings generate a varying magnetic field that rotates an impeller within the housing bore to pump fluid along the housing bore A monitor logic to monitor a set of sensors to obtain information about one or more of fluid temperature, fluid pressure, and device temperature; and a control logic to adjust performance of the booster pump based on the information obtained from the set of sensors.

In a variation on this aspect, a first end of the external tray hose assembly is coupled at the server tray via a first fluid coupler. A second end of the external tray hose is coupled to a fluid supply channel via a second fluid coupler. The first fluid coupler is attached to the first end of the external tray hose. The second fluid coupler is attached to the second end of the external tray hose.

In a variation on this aspect, the booster pump is electrically coupled to a power and a control source, the power source and the control source providing power and control to the booster pump.

In a variation on this aspect, the external tray hose can include a swappable tube with a mechanism to decrease repair and/or replacement time in an event of failure of the booster pump.

In a further variation on this aspect, the apparatus can further include: a coolant distribution unit which includes a coolant distribution unit pump to pump the coolant fluid toward the computing device on the server tray; and the booster pump to boost fluid flow and fluid pressure of the coolant fluid pumped out by the coolant distribution unit pump.

In a further variation, the microaxial booster can be attached to a server in a chassis to ensure a flow that matches with flows associated with other servers in the chassis, wherein the server in the chassis has a different fluid pressure drop when compared to the other servers in the chassis.

In a further variation, the apparatus can further include an analysis logic to determine, based on the information obtained from the set of sensors, whether fluid pressure of the booster pump is to be adjusted; and the control logic to adjust, in response to determining that the fluid pressure of the booster pump is to be adjusted, the fluid pressure of the booster pump.

In another aspect, the apparatus can include a booster pump mounted within a server tray, the booster pump to boost fluid flow and fluid pressure of coolant fluid pumped toward a computing device on a server tray. The booster pump includes a stator mounted around booster pump housing with a bore. The stator includes one or more C-shaped lamination stacks for supporting coil windings. Energized coil windings generate a varying magnetic field that rotates an impeller within the housing bore to pump fluid along the housing bore. A monitor logic monitors a set of sensors to obtain information about one or more of fluid temperature, fluid pressure, and device temperature. A control logic to adjust performance of the booster pump based on the information obtained from the set of sensors.

In a variation of this aspect, the booster pump can be mounted within the server tray and be coupled to another pump on the server tray to pump the coolant fluid serially towards the computing device.

In a variation of this aspect, the booster pump mounted within the server tray is coupled to another pump on the server tray to pump coolant fluid in parallel towards the computing device.

One aspect described in this application can provide a system and method for boosting fluid flow and for adjusting performance of the booster pump. During operation, the system can receive, at a booster pump integrated into an external tray hose, a coolant fluid from a coolant distribution unit, wherein the booster pump comprises a stator mounted around booster pump housing with a bore, wherein the stator includes one or more C-shaped lamination stacks for supporting coil windings, and wherein energized coil windings generate a varying magnetic field that rotates an impeller within the housing bore to pump fluid along the housing bore. The system can boost fluid flow and fluid pressure of the coolant fluid pumped toward a computing device that is to be cooled on a server tray; and adjust performance of the booster pump based on the information associated with the set of sensors, wherein the information includes one or more of fluid temperature, fluid pressure, and device temperature.

The methods and processes described in the detailed description section can be embodied as code and/or data, which can be stored in a computer-readable storage medium as described above. When a computer system reads and executes the code and/or data stored on the computer-readable storage medium, the computer system performs the methods and processes embodied as data structures and code and stored within the computer-readable storage medium.

Furthermore, the methods and processes described above can be included in hardware modules or apparatus. The hardware modules or apparatus can include, but are not limited to, ASIC chips, field-programmable gate arrays (FPGAs), dedicated or shared processors that execute a particular software module or a piece of code at a particular time, and other programmable-logic devices now known or later developed. When the hardware modules or apparatus are activated, they perform the methods and processes included within them.

The foregoing descriptions of aspects have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the scope of this disclosure to the forms disclosed. Accordingly, many modifications and variations will be apparent to practitioners skilled in the art.

What is claimed is:

1. An apparatus, comprising:

a booster pump integrated into an external tray hose, the booster pump to boost fluid flow and fluid pressure of coolant fluid pumped toward a computing device on a server tray, wherein the external tray hose comprises a first hose portion comprising a first end of the external tray hose and a second hose portion comprising a second end of the external tray hose, wherein the booster pump is integrated into the external tray hose between the first and second hose portions, wherein the first end is configured to be removably coupled to a supply coupler of a server tray and the second end is configured to be removably coupled to a fluid supply channel of a rack that houses the server tray, wherein the booster pump comprises a stator mounted on a booster pump housing with a bore, wherein the stator includes one or more C-shaped lamination stacks for supporting coil windings, and wherein energized coil windings generate a varying magnetic field that rotates an impeller within the housing bore to pump fluid along the housing bore;

a monitor module to monitor a set of sensors to obtain information about one or more of fluid temperature, fluid pressure, and computing device temperature; and

a control module to adjust performance of the booster pump based on the information obtained from the set of sensors.

2. The apparatus of claim **1**, wherein the booster pump is electrically coupled to a power source and the control module, the power source providing power to the booster pump.

3. The apparatus of claim **1**, wherein the external tray hose includes a swappable tube with a self-sealing quick disconnect fluid coupler, or a combination of a valve and a fluid coupler, at each of the first end and the second end.

4. The apparatus of claim **1**, further comprising:

a coolant distribution unit including a coolant distribution unit pump to pump the coolant fluid toward the computing device on the server tray;

wherein the booster pump is to boost fluid flow and fluid pressure of the coolant fluid pumped out by the coolant distribution unit pump.

5. The apparatus of claim **1**, wherein the booster pump is attached to a server in a chassis to ensure a flow that matches with flows associated with other servers in the chassis; and wherein the server in the chassis has a different fluid pressure drop with respect to the other servers in the chassis.

6. The apparatus of claim **1**, further comprising:

an analysis module to determine, based on the information obtained from the set of sensors, whether fluid pressure of the booster pump is to be adjusted; and

the control module to adjust, in response to determining that the fluid pressure of the booster pump is to be adjusted, the fluid pressure of the booster pump.

7. A method, comprising:

receiving, at a booster pump integrated into an external tray hose, a coolant fluid from a coolant distribution unit, wherein the external tray hose comprises a first hose portion comprising a first end of the external tray hose and a second hose portion comprising a second end of the external tray hose, wherein the booster pump is integrated into the external tray hose between the first and second hose portions, wherein the first end is configured to be removably coupled to a supply coupler of a server tray and the second end is configured to be removably coupled to a fluid supply channel of a rack that houses the server tray, wherein the booster pump comprises a stator mounted around booster pump housing with a bore, wherein the stator includes one or more C-shaped lamination stacks for supporting coil windings, and wherein energized coil windings generate a varying magnetic field that rotates an impeller within the housing bore to pump fluid along the housing bore;

boosting, by the booster pump, fluid flow and fluid pressure of the coolant fluid pumped toward a computing device that is to be cooled on a server tray;

monitoring, by a set of sensors, one or more of fluid temperature, fluid pressure, and computing device temperature; and

adjusting performance of the booster pump based on information output by the set of sensors, wherein the information is indicative of the monitored one or more of fluid temperature, fluid pressure, and device temperature.

8. The method of claim **7**, wherein the booster pump mounted on the server tray is coupled in series to another pump on the server tray to pump the coolant fluid serially towards the computing device.

9. The method of claim **7**, wherein the booster pump mounted on the server tray is coupled in parallel to another pump on the server tray to pump coolant fluid towards the computing device.

10. The method of claim **7**, wherein the external tray hose includes a swappable tube with a self-sealing quick disconnect fluid coupler, or a combination of a valve and a fluid coupler, at each of the first end and the second end.

11. The method of claim **7**, wherein the booster pump is attached to a server in a server chassis to ensure a flow that matches with flows associated with other servers in the server chassis, wherein the server in the server chassis has a different fluid pressure drop when compared to the other servers in the server chassis.

12. The method of claim **7**, wherein adjusting performance of the booster pump based on the information associated with the set of sensors further comprises:

reducing speed of the booster pump.

13. The method of claim **7**, wherein adjusting performance of the booster pump based on the information associated with the set of sensors further comprises:

increasing speed of the booster pump.

14. The method of claim **7**, further comprising:

boosting, by the booster pump, fluid flow and fluid pressure of the coolant fluid pumped out by a coolant distribution unit pump, wherein the coolant distribution unit includes the coolant distribution unit pump to pump the coolant fluid toward the computing device on the server tray.

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